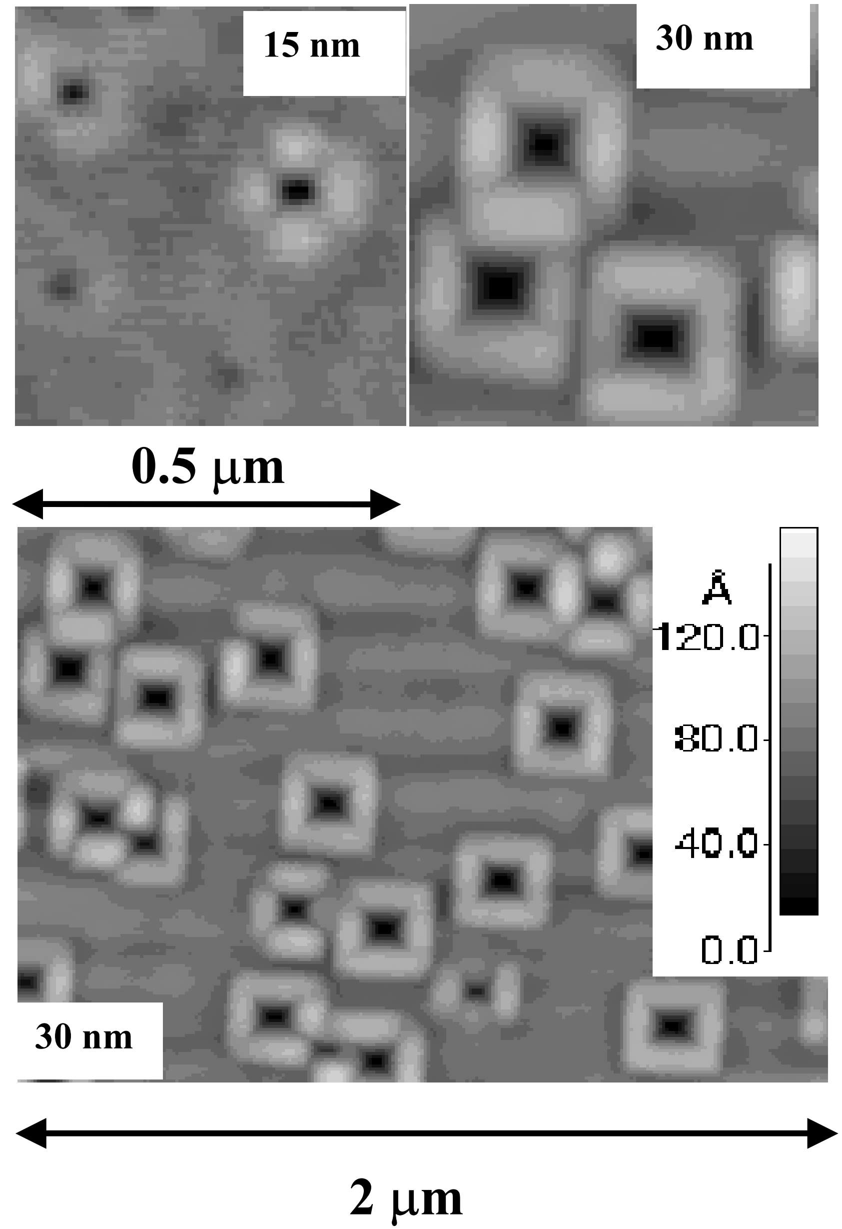
Self Assembly of "Quantum Fortresses"

- **Self assembling quantum dot quadruplets form during epitaxy of GeSi alloys on Si**
- **Square pits form first, followed by assembly of islands on each edge of the pit**
- **Nature forming what we cannot directly engineer on such fine scales**
- **Jennifer Gray, Robert Hull (UVa), Jerry Floro (Sandia)**



DMR-0075116; Robert Hull/UVA

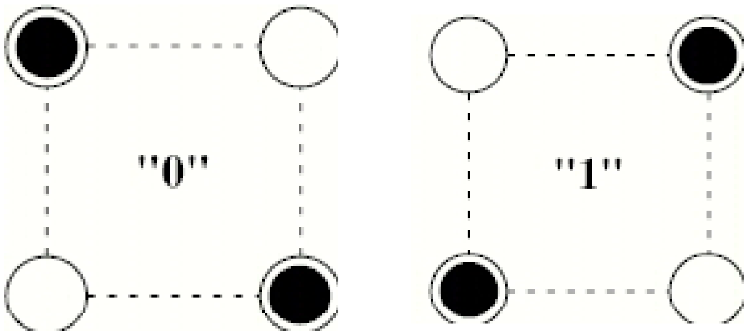
Growth conditions: $Ge_{0.3}Si_{0.7}$/Si(100), 550 C, 0.9 A/s. AFM images with $Ge_{0.3}Si_{0.7}$ epitaxial layer thickness shown in each case.

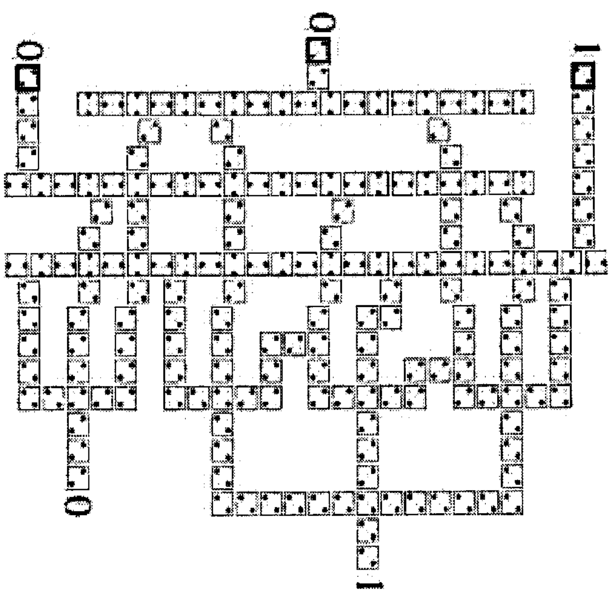
This is a Focused Research Group project involving collaborations between researchers at UVA, U. IL, IBM, and Sandia. The project seeks to quantify, understand and predictively model the competition and coordination between generation of atomic-scale crystalline line defects, known as dislocations, and atomic-scale roughening of surfaces, both of which relieve internal stresses when two crystal lattices with different inter-atomic spacings are combined. The program focuses on layered thin films of different semiconductor materials that have significant potential in microelectronics technology. Defects and non-planar morphologies in these structures can significantly impair desired optical or electronic properties of conventional electronic and optoelectronic device structures. Conversely, the controlled formation of small islands ("quantum dots") of crystalline material during thin film growth processes can enable new nano-scale electronic architectures.

This specific result relates to the controlled formation of a novel surface morphology called "quantum fortresses". As seen in the first slide, these comprise quadruplets of islands, one island forming on each wall of shallow pits that form during growth of crystalline germanium (30%) – silicon (70%) alloy layers on a single crystal silicon substrate. During growth, the shallow pits first form in the growing GeSi alloy layer as a method of relaxing the high stresses induced in the film by different inter-atomic spacings in Si and Ge. During subsequent growth, islands form around the pits to produce regular quadruplets. With further growth the islands elongate to form a continuous wall around the pits. These structures are observed over a range of growth conditions. However they are not equilibrium structures but rather are stabilized by specific conditions of growth temperature and deposition rate where the resultant atomic mobilities on the growing surface favor this complex morphology.

These structures have potential application in a novel nano-scaled microelectronic architecture called "quantum cellular automata" (QCA). The QCA concept is based on the introduction of two extra electronic charges onto a quadruplet of closely spaced clusters of material. As shown in the second slide, electric repulsion between these extra electrons forces them into occupancy of opposite corners of the cell, forming two allowed states. These two states simulate the "0" and "1" states of conventional digital electronics. Aligning these cells into patterns (as for the adder circuit shown on the same slide) allow digital circuits to be formed. Such circuits could have much higher densities and much lower power consumption than conventional microelectronic circuits, but to operate at practical temperatures they have to be very small: cluster sizes and separations of just a few hundred atomic spacings are required, which is beyond the limit of conventional fabrication techniques. But in the structures presented here, nature is forming just such structures spontaneously. If we can directly control the formation of the quantum fortress structures (for example by directly seeding the precursor pit formation), novel nano-electronic architectures such as QCAs may be realizable.

Quantum Cellular Automata





- Exploration of new nanoelectronic architectures – electronics beyond the MOSFET?
- Collaborations between industry and government labs: broader experience / perpsective for graduate students
- Extrapolation of basic research to potential technological applications
- Multi-disciplinary research